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From:
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Date:
March 19, 2013

ARCADIS Project No.:
B0064583.0004.00907

Subject:
King Highway Landfill OU – Flow Reversal Determination Prior to Groundwater Sampling Events

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This technical memorandum provides a process for assessing the potential for groundwater flow reversal conditions at the King Highway Landfill (KHL) using real-time flow data from the United States Geological Survey's (USGS) Comstock River Gage Station[1] (Comstock gage), which is located approximately 2 miles upstream of the KHL. Refer to Figure 1 for the location of the KHL and the Comstock gage. The Michigan Department of Environmental Quality (MDEQ) has typically required that 2 weeks of elevation data be collected prior to groundwater sampling at the site to assess potential groundwater flow reversal conditions. The process in this technical memorandum was developed to help determine whether using river flow data available via the Internet from the USGS gage at Comstock could replace the physical collection of river and groundwater elevation data by a sampling crew. To develop this process, existing groundwater and Kalamazoo River elevation data were used to assess whether the occurrence of groundwater flow reversal conditions at the KHL can be predicted remotely from river flow data from the Comstock gage. This technical memorandum presents four sections: Groundwater Flow and Data Evaluation, Seasonal Flow Analysis, Process, and Recommendation.

Groundwater Flow and Data Evaluation

Groundwater beneath the KHL is derived from infiltration of precipitation falling on uncapped portions of the site and from groundwater entering the site from areas of higher hydraulic head. The majority (approximately 75%) of the KHL site was capped as a component of the remedial action implemented in accordance with the February 2000 Administrative Order by Consent signed by MDEQ. Capping reduces the amount of recharge to the groundwater table over the

[1] http://waterdata.usgs.gov/usa/nwis/uv?04106000

area covered by the cap, and increases the volume of water directly entering the river via surface runoff. Therefore, a majority of the groundwater flowing beneath the KHL enters the river from upland areas generally to the west and southwest. The water table beneath the KHL is principally in the upper-sand unit, but also likely occurs in the paper-making residuals in portions of the former landfill cells. As a result, shallow groundwater flows toward, and discharges to, the Kalamazoo River. However, based on elevation data collected from the river (KHL river staff gage RG-6) and groundwater (monitoring well MW-3AR) during past 8 years of groundwater monitoring events, there are times when the river water elevation can be slightly higher than the groundwater elevation, which is in theory a negative gradient. The MDEQ has expressed concern that this could be indicative of reversed flow (i.e., flow from the river to the groundwater) and could potentially dilute the concentration of any contaminants in groundwater contributed by the KHL, which would affect groundwater monitoring results.

To assess whether groundwater flow reversal conditions at the KHL can be predicted remotely from the Comstock gage, the following data collected from November 18, 2002 through August 27, 2010 were used:

- Groundwater elevation data from existing monitoring well MW-3AR
- Kalamazoo River elevation data from the river staff gage RG-6
- Flow data from Comstock gage

Monitoring well MW-3AR and river staff gage RG-6 were used for the assessment due to their proximity (75 feet) to each other (Figure 2), which provides a relationship that defines the geometry of the water table relative to surface water. Without river staff gage RG-6, the river elevation adjacent to any of the site monitoring wells would need to be estimated based on an assumed river elevation slope, and, as such, would create some uncertainty.

To evaluate the relationship between flow measured at the Comstock gage and the gradient between monitoring well MW-3AR and river staff gage RG-6, the daily average flow data at Comstock gage were plotted against corresponding elevation data from RG-6 and MW-3AR. The results show that the instantaneous flows at the Comstock gage are significantly correlated ($p<0.01$ and $\alpha=0.05$) to water elevation in RG-6 (Chart 1) and groundwater elevation in MW-3AR (Chart 2). "Significantly correlated" means that there is less than 1 percent chance that the Comstock gage flows and water elevations at RG-6 and MW-3AR are randomly related. These plots indicate that the groundwater elevations and river flow tend to rise and fall together in a very predictable way, as indicated by the R^2 values (0.844 and 0.936 for RG-6 and MW-3AR, respectively). Based on the R^2 values, the Comstock gage flow data would be a good predictor of river elevation at RG-6 and groundwater elevation at MW-3AR.

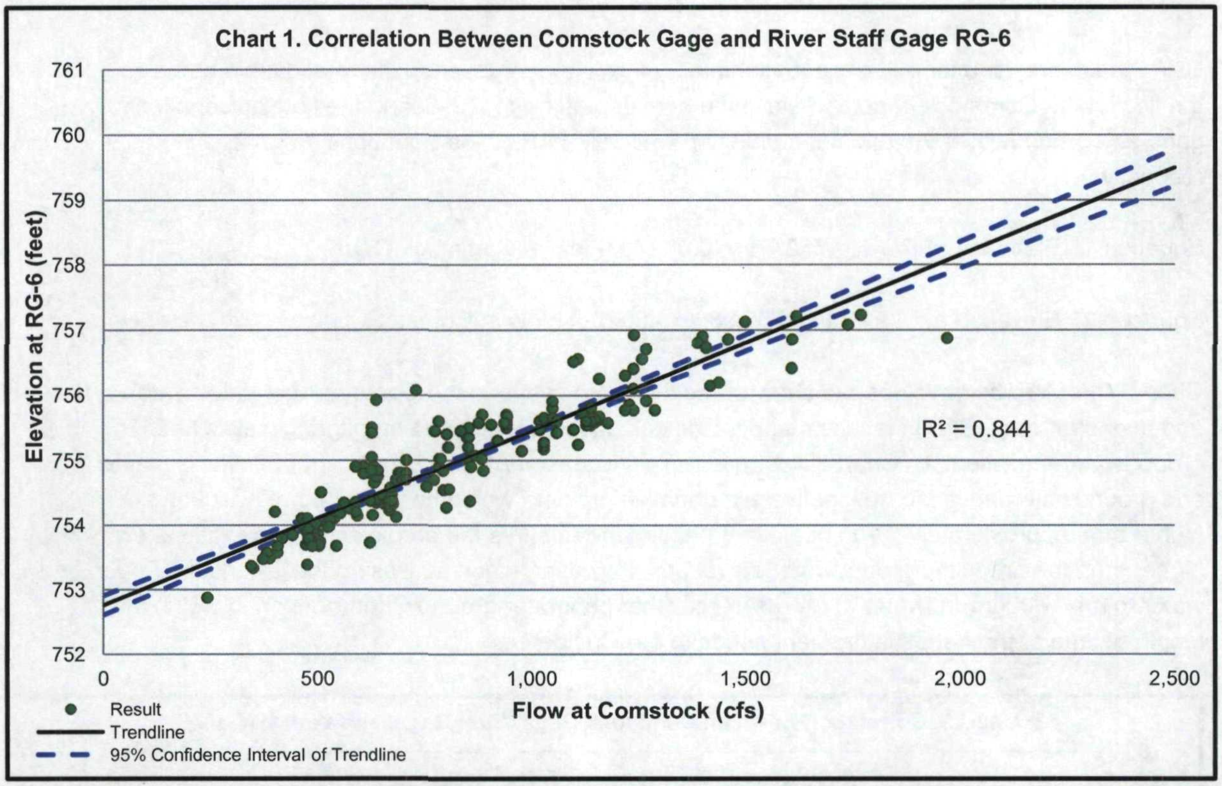


Chart 1. Correlation Between Comstock Gage and River Staff Gage RG-6
Elevation at RG-6 (feet)
761
760
759
758
757
756
755
754
753
752
0
500
1,000
1,500
2,000
2,500
Flow at Comstock (cfs)
R² = 0.844
Result
Trendline
95% Confidence Interval of Trendline

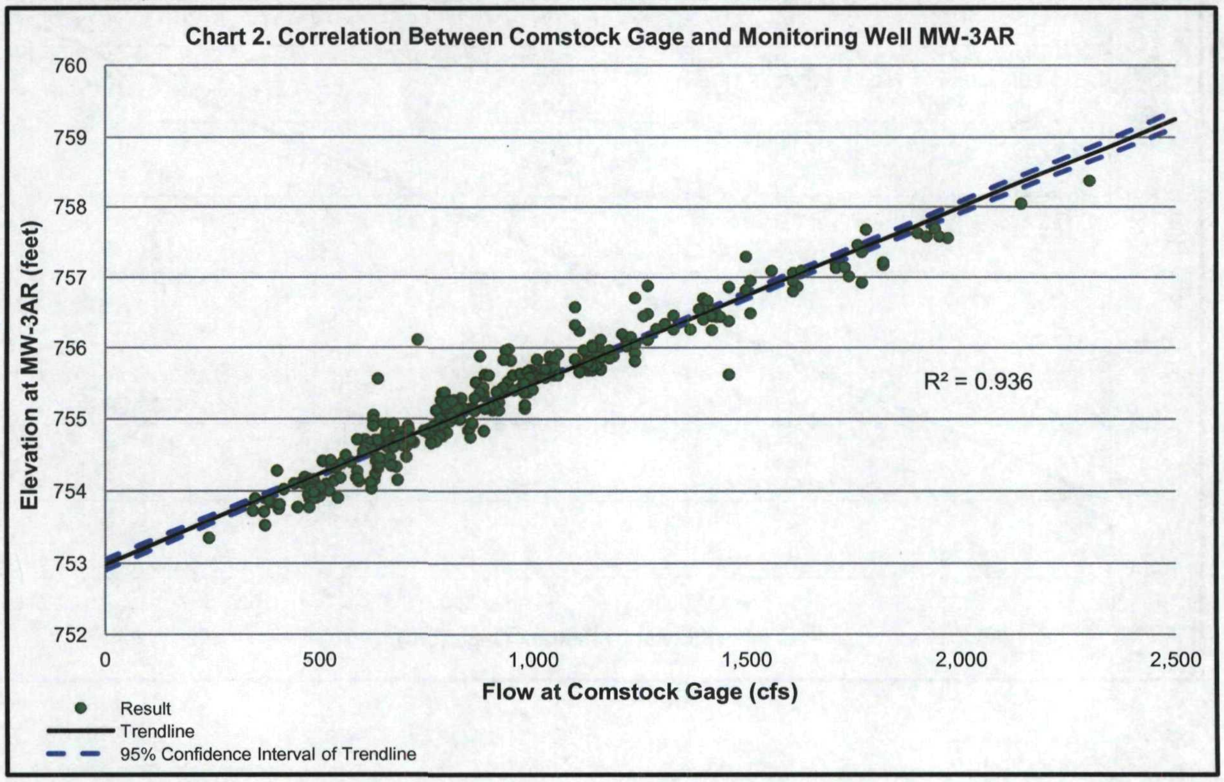


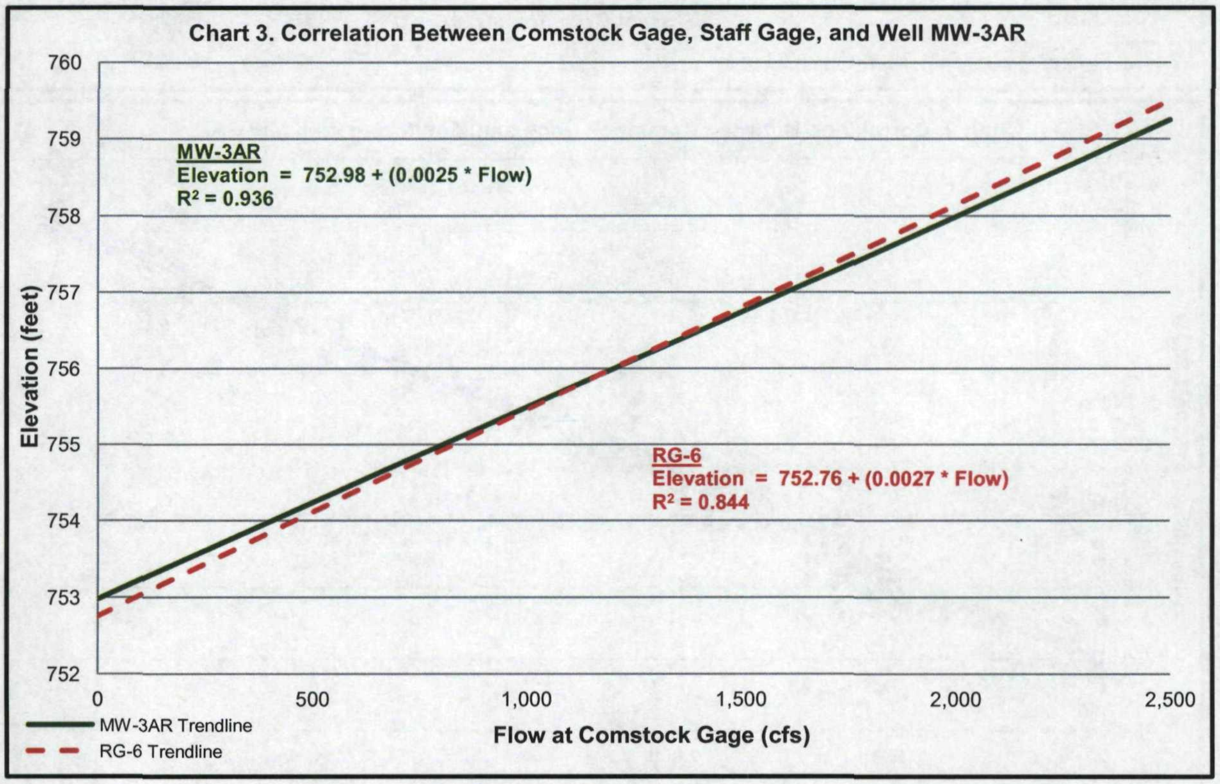
Chart 2. Correlation Between Comstock Gage and Monitoring Well MW-3AR
Elevation at MW-3AR (feet)
760
759
758
757
756
755
754
753
752
0
500
1,000
1,500
2,000
2,500
Flow at Comstock Gage (cfs)
R² = 0.936
Result
Trendline
95% Confidence Interval of Trendline

Using the expression for a linear equation (i.e., y = b + mx) to describe the relationship between the flow at the Comstock gage and elevation at river staff gage RG-6, and the flow at Comstock gage and groundwater elevation at monitoring well MW-3AR yields Eqautions 1 and 2, respectively.

Equation 1: Elevation at RG-6 = 752.76 + (0.0027 × Flow at Comstock Gage)

Equation 2: Elevation at MW-3AR = 752.98 + (0.0025 × Flow at Comstock Gage)

Chart 3 (below) was developed to show the relationship between the Comstock gage flow rate and river staff gage RG-6 elevation, and Comstock gage flow rate and monitoring well MW-3AR groundwater elevation. As Chart 3 illustrates, using Equations 1 and 2 to determine river elevation and groundwater elevation, respectively, a negative gradient would be predicted at river flows higher than approximately 1,100 cubic feet per second (cfs), as the predicted river elevations are higher than the predicted groundwater elevations. However, when assessing the potential for river water to mix with groundwater at MW-3AR (or other perimeter groundwater monitoring wells) the length of time of the negative gradient needs to be considered.



At the request of MDEQ, correlation plots were developed showing the relationship of the groundwater elevation at other shallow monitoring wells (i.e., MW-8AR, MW-12AR, MW-13AR, MW-14AR, MW-15AR, and MW-16A), and the Comstock gage flow rate; and the relationship of the groundwater elevation at these same shallow wells and the estimated river elevation adjacent to the wells. The correlation plots between each near-shore, shallow monitoring wells and river flow measured at the Comstock gage are shown on Charts 4 through 9 in Attachment A. Additionally, charts 10 through 15 (Attachment A) show the relationship between the Comstock gage flow rate and a predicted river elevation based on an assumed uniform river slope estimated **using data from the Remedial Investigation's RG**-3 and RG-5 staff gages. The adjustment values identified in the table in Attachment A have been included in Standard Operating Procedure E, *Groundwater Sampling Procedures*, of the DRAFT FINAL *Operation and Maintenance Plan*, which will be used to estimate the river elevation adjacent to each of the shallow monitoring wells located along the river.

In order to have surface water flow from the river to a monitoring well, the gradient would need to be sustained for a period of time that is influenced by the distance from the surface water to the well, the hydraulic gradient, and the properties of the soil. The following equation was used to estimate the amount of time required for surface water to flow from the river to the wells:

$$\overline{\mathrm{v}} = \frac{(\mathrm{K} \times \mathrm{I})}{\mathrm{n_e}}$$

$\overline{\mathrm{v}}$ = average linear velocity;
K = hydraulic conductivity;
I = hydraulic gradient; and
n_e = effective porosity.

The hydraulic conductivity measurements for the native river deposits, as reported in Technical Memorandum 6 for the KHL (BBL, 1994), range from $1.0E^{-2}$ to $2.5E^{-2}$ centimeter per second. Because hydraulic conductivity values for the paper-making residuals are several orders of magnitude lower, using the values for the native river deposits results in a conservative time estimate.

The graphic presentation of the elevations at monitoring well MW-3AR and river staff gage RG-6, Chart 3 (above), illustrates that when there is a higher hydraulic head in the river compared to groundwater, the elevation difference is slight, generally less than 0.5 foot, and typically much lower. In order to provide a conservative estimate, a hydraulic gradient of 0.01 was used, based on an elevation change of 0.5 foot over a distance of 36 feet between monitoring well MW-3AR and river staff RG-6. Using an estimated effective porosity value of 0.2, the average linear velocity is approximately 1.4 to 3.5 feet/day. Using these values, the gradient difference of 0.5 foot between the river and the wells would need to be maintained for approximately 10 to 25 days to allow river water to reach monitoring well MW-3AR at a distance of 36 feet from the river.

Tables 1 and 2 below provide the distances from each of the KHL monitoring wells to the Kalamazoo River and the time required for river water to reach each shallow monitoring well within the range of hydraulic conductivities for the native sand unit. Based on the distances provided below, monitoring well MW-3AR is representative of the other downgradient monitoring wells on-site that are closest to the river and therefore, most likely to be affected by flow reversal conditions.

Table 1 - Time Required for River Water to Reach Well Using Hydraulic Conductivity of $3.2E^{-4}$ Feet Per Second ($1.0E^{-2}$ Centimeters Per Second)

Monitoring Well ID	Distance to River (feet)	Time Required to Reach River (days)
MW-3AR	36	26.0
MW-8AR	19	13.7
MW-11RR	61	44.1
MW-12AR	27	19.5
MW-13AR	21	15.2
MW-14AR	40	28.9
MW-15AR	29	21.0
MW-16A	19	13.7

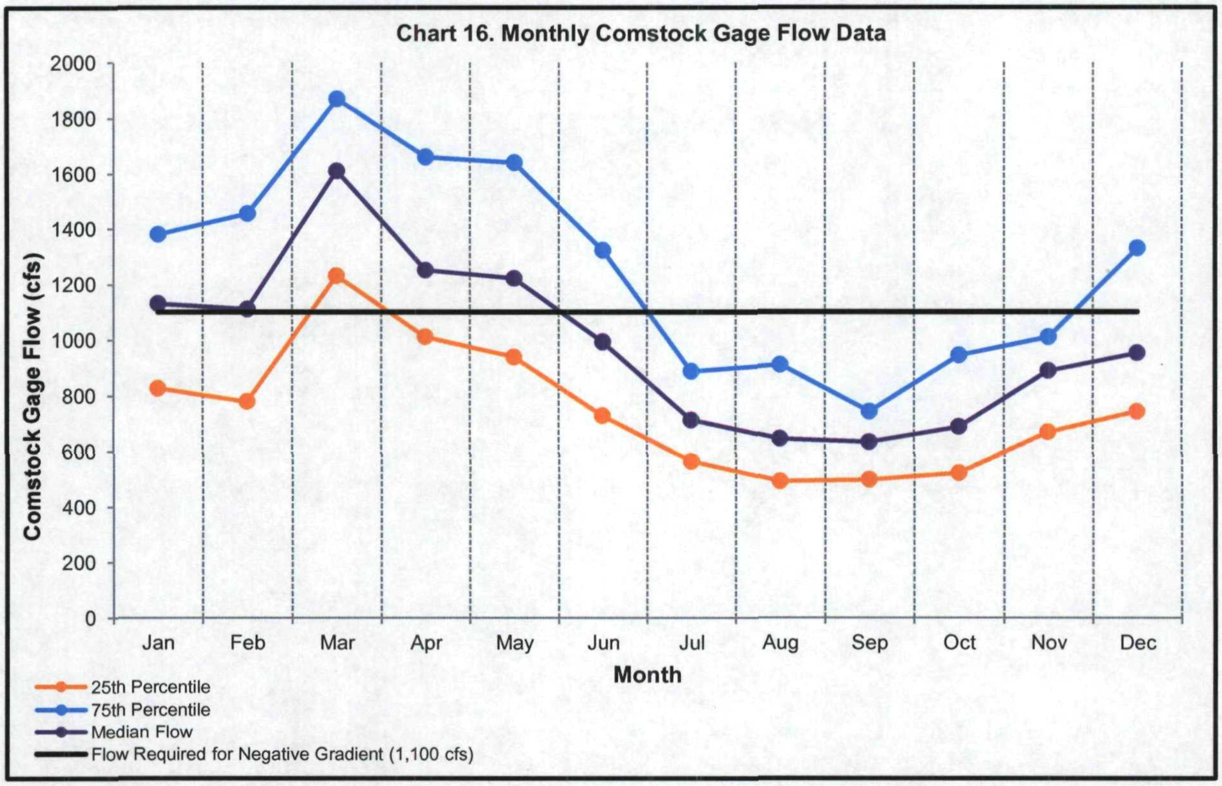
Table 2 - Time Required for River Flow to Reach Well Using Hydraulic Conductivity of $8.2E^{-4}$ Feet Per Second ($2.5E^{-2}$ Centimeters Per Second)

Monitoring Well ID	Distance to River (feet)	Time Required to Reach River (days)
MW-3AR	36	10.2
MW-8AR	19	5.4
MW-11RR	61	17.2
MW-12AR	27	7.6
MW-13AR	21	5.9
MW-14AR	40	11.3
MW-15AR	29	8.2
MW-16A	19	5.4

Seasonal Flow Analysis

The 2002 to 2012 flow rate measured at the Comstock gage was analyzed to determine the seasonal variation of the flow rate within the Kalamazoo River (Chart 4). Based on this analysis, the median flow rate of the Kalamazoo River for the months of January through May, as measured at the Comstock gage, was greater than the flow rate predicted from the analysis above to indicate presence of a negative gradient at the KHL (i.e., 1,100 cfs). Conversely, during the months of June through December, the median flow rate at the Comstock River gage was less than 1,100 cfs, with the lowest median flow rate measured during the months of August and September. Furthermore, the 75th percentile flow measured at the Comstock gage for the months of July through November were less than the flow required for a negative gradient at the KHL.

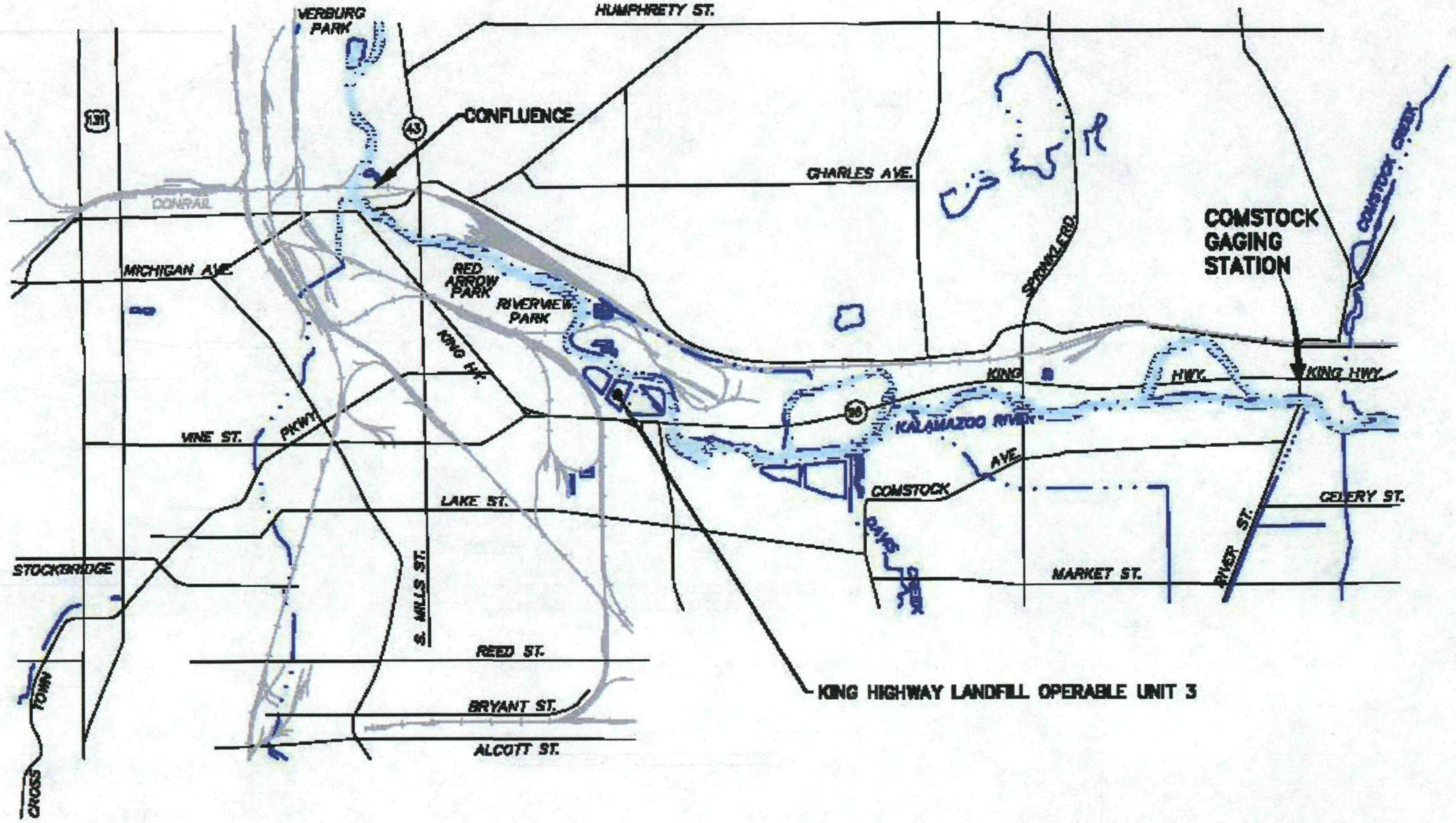
These data indicate the best timeframe for conducting the annual groundwater sampling event would be during the months of July through November, when the potential for a negative gradient at the KHL is the lowest.



Process

Based on the information and evaluation above, the following process is proposed for assessing groundwater flow conditions at the KHL prior to groundwater sampling. Two weeks prior to the expected start of the groundwater sampling event, the flow rates measured at the Comstock gage would be monitored via the Internet for flow rate trend data of the Kalamazoo River for the two week period. If the flow rate is below 1,100 cfs, or near 1,100 cfs and trending lower, the groundwater sampling event will be scheduled.

For the two-week period prior to the scheduled sampling date, the flow rate of the Kalamazoo River will continue to be monitored using the Comstock gage station website, recording the daily average flow for at least 7 days prior to the scheduled start of sampling. If the flow rate is below 1,100 cfs and the river flow rate remains at steady state or there is a downward trend in the flow rate for the one-week monitoring period, then the sampling crew will mobilize to the KHL. If the flow rate is not below 1,100 cfs and there is no downward trend in the river flow rate, Georgia-Pacific (or ARCADIS) will consult the MDEQ Project Coordinator to determine whether to proceed with mobilizing to the KHL as scheduled, or to reschedule the sampling event.



NOTES:

1. PLANIMETRIC MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEMS.

0 2400' 4800'

GRAPHIC SCALE

ALLIED PAPER, INC./PORTAGE CREEK/
KALAMAZOO RIVER SUPERFUND SITE
FLOW REVERSAL DETERMINATION PRIOR TO ANNUAL GROUNDWATER SAMPLING EVENTS

SITE LOCATION MAP

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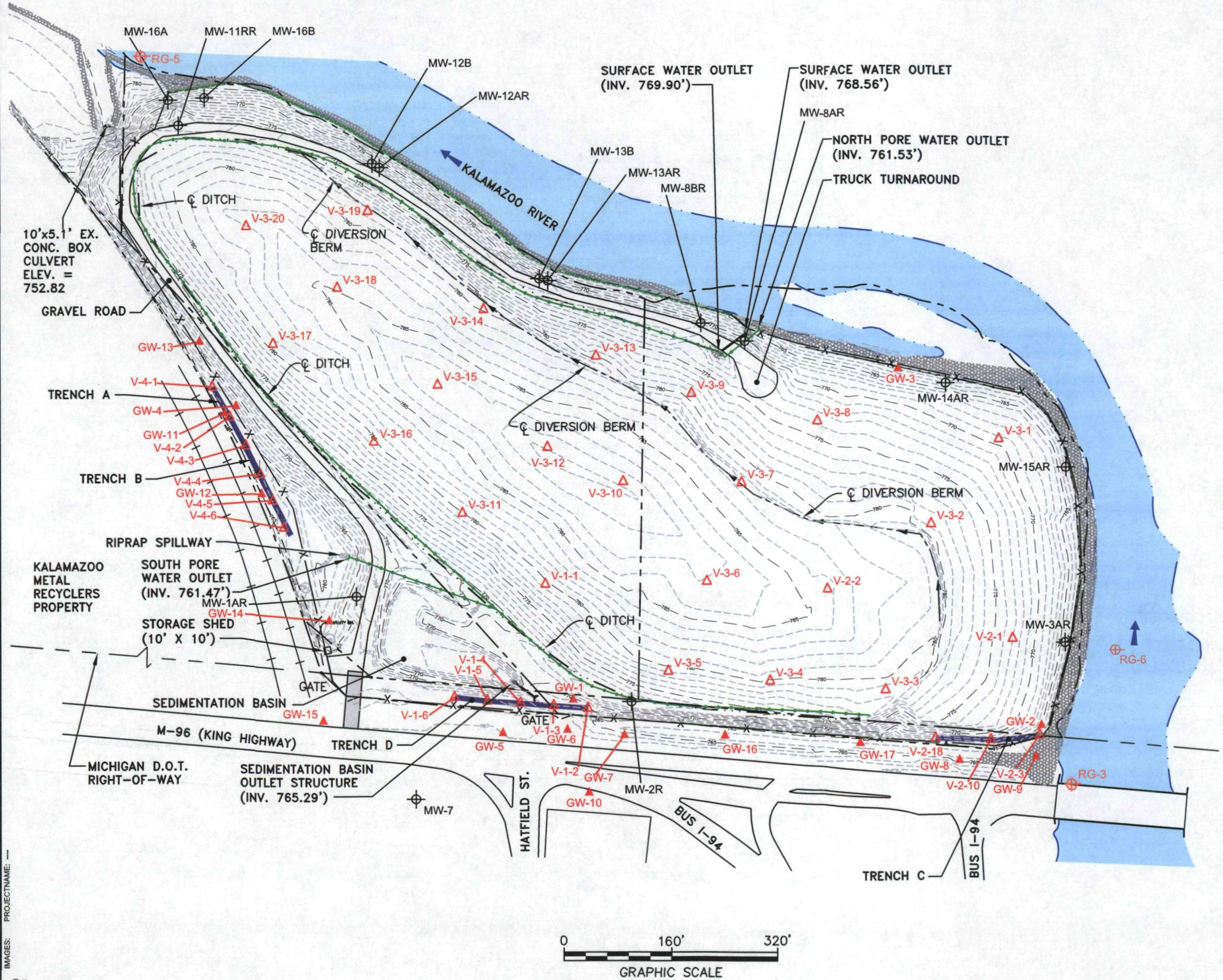
FIGURE
1



LEGEND:

- APPROXIMATE PARCEL BOUNDARY
- DITCH LINE
- ABANDONED RAILROAD
- SHEETPILE WALL
- ACCESS ROAD
- RIPRAP
- CULVERT PIPE
- FINAL AS-BUILT INDEX CONTOUR
- FINAL AS-BUILT INTERMEDIATE CONTOUR
- SECURITY FENCE
- PORE WATER COLLECTION PIPE
- PORE WATER DRAIN
- APPROXIMATE WATER EDGE
- V-1-2 GAS VENTS
- LANDFILL GAS CUTOFF TRENCH
- FLOW DIRECTION
- MW-14 MONITORING WELL
- RG-3 FORMER RIVER GAUGE STATION (NO LONGER IN USE)
- GW-2 LOCATION OF GAS MONITORING PROBES

NOTES:

1. BASE MAP INFORMATION OBTAINED FROM CADD DRAWING FILE DEVELOPED BY RMT, INC., ANN ARBOR, MICHIGAN (CADD FILE: L1630SU01.DWG AS-BUILT SURVEY; 8/21/00).
2. FINAL AS-BUILT CONTOUR ELEVATIONS ARE SHOWN AND ARE BASED ON A FIELD SURVEY BY ATWELL-HICKS, INC., DATED 9/27/00 WITH REVISIONS DATED 10/23/00, 12/21/01, 12/10/02, AND 7/24/03.
3. ELEVATIONS ARE BASED ON NGVD OF 1929 (MSL).
4. PROPERTY SURVEY PERFORMED BY WILKINS & WHEATON ENGINEERING CO., INC., ON 7/1/96.
5. TOPOGRAPHIC CONTOUR INTERVAL IS 1 FOOT.
6. LOCATIONS OF GW-5, GW-6, GW-7, GW-8, GW-9, AND GW-10 ARE BASED ON A FIELD SURVEY BY TERRA CONTRACTING LLC, DATED 9/23/05.
7. LOCATION OF GW-11 IS BASED ON A FIELD SURVEY BY TERRA CONTRACTING LLC, DATED 1/11/06.
8. LOCATIONS OF RG-6, V-4-4, V-4-5, AND V-4-6 ARE BASED ON A FIELD SURVEY BY TERRA CONTRACTING LLC, DATED 6/7/06.
9. LOCATIONS OF V-1-2 THROUGH V-1-6, V-2-3, V-2-10, AND V-2-18 ARE BASED ON MULTIPLE FIELD SURVEYS CONDUCTED BY TERRA CONTRACTING, LLC. IN APRIL 2008. GAS VENTS V-2-4 THROUGH V-2-9, AND V-2-11 THROUGH V-2-17 ARE NOT SHOWN FOR CLARITY PURPOSES (THESE VENTS ARE LOCATED ALONG TRENCH C).
10. LOCATION OF GW-12 IS APPROXIMATE.
11. LOCATIONS OF GW-13 THROUGH GW-17 BASED ON FIELD SURVEY CONDUCTED BY PREIN & NEWHOF ON 11/1/11.

ALLIED PAPER, INC./PORTAGE CREEK/
KALAMAZOO RIVER SUPERFUND SITE

FLOW REVERSAL DETERMINATION PRIOR TO ANNUAL GROUNDWATER SAMPLING EVENTS

KHL SITE PLAN

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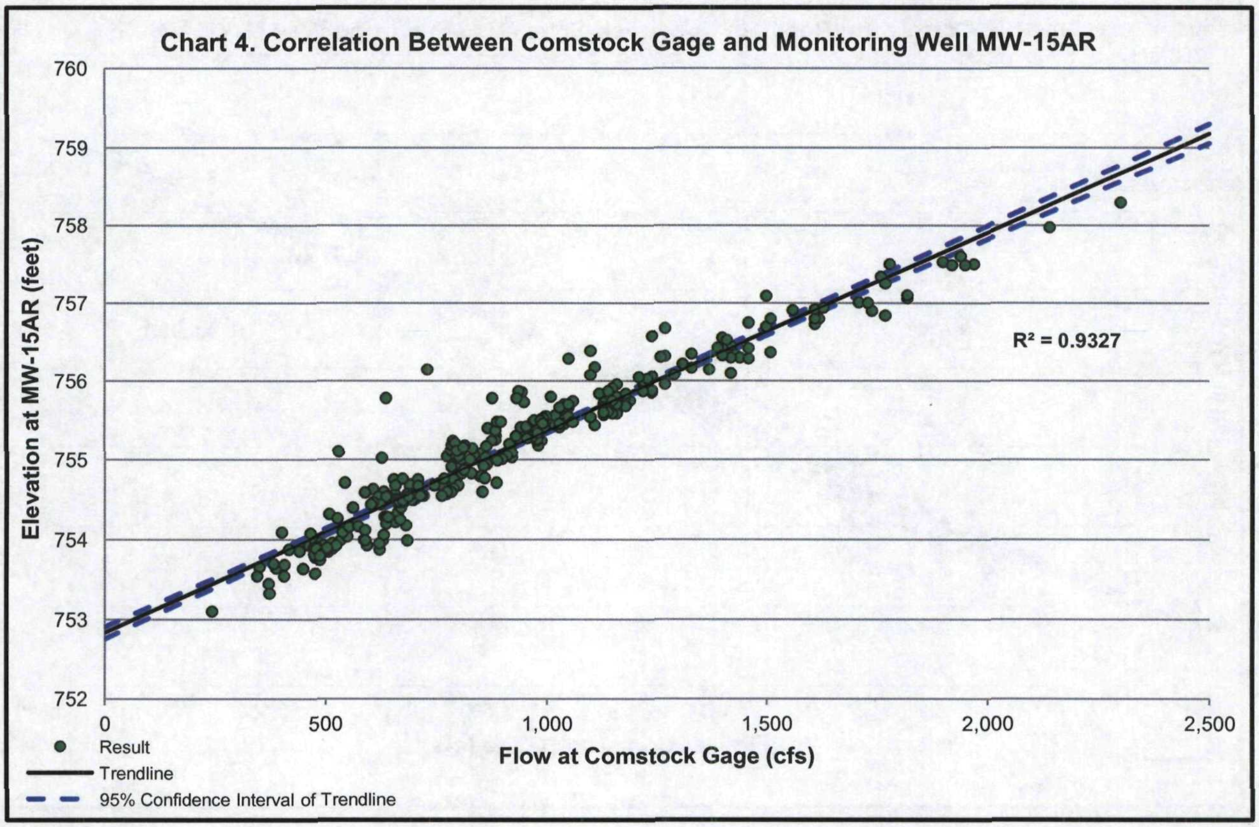
FIGURE
2

The river surface elevations collected at river staff gages RG-3 and RG-5, provided in the July 1996 Remedial Investigation (RI) Report for the King Highway Landfill Operable Unit 3, were correlated to river flow. Staff gage RG-3 was located within the river adjacent to the southeastern corner of the KHL, whereas staff gage RG-5 was located within the river adjacent to the northwestern corner of the KHL (Figure 2). These two river gages bound the upstream (southern) and downstream (northern) extent of the river segment adjacent to the KHL. Using the RG-3 and RG-5 river elevations, the average difference in river elevation across the site (between RG-3 and RG-5) was calculated to be 0.38 feet. For the near-shore monitoring wells located downstream of monitoring well MW-3AR, the regression equation for staff gage RG-6 [i.e., Elevation = 752.76 + (0.0027 * Flow)] was used, with the y-intercept adjusted to reflect the river's gradient over the distance between the specified well and staff gage RG-6. The river elevation adjustment for each near shore monitoring well is listed in the table below. The relationship between groundwater elevation and the flow measured at the USGS Comstock gage for each near shore monitoring well is shown on Charts 4 through 9. The results from correlating river elevation and groundwater elevation for each near shore monitoring well are shown in Charts 10 through 15, below, starting at the furthest upstream monitoring well and ending at the furthest downstream monitoring well.

Monitoring Well	Elevation Adjustment from Calculated River Elevation at RG-6 (feet)
MW-3AR	-0.00
MW-15AR	-0.05
MW-14AR	-0.11
MW-8AR	-0.17
MW-13AR	-0.22
MW-12AR	-0.27
MW-16A	-0.34



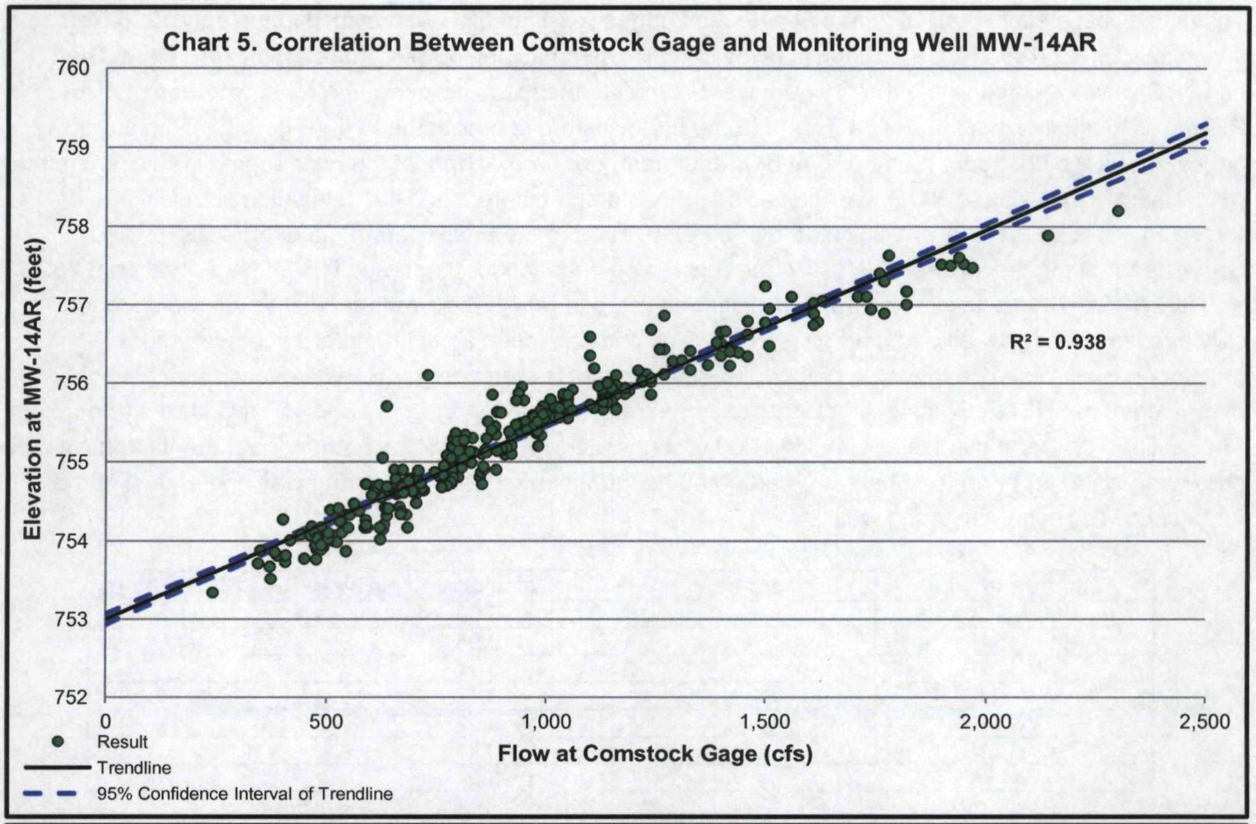


Chart 5. Correlation Between Comstock Gage and Monitoring Well MW-14AR
Elevation at MW-14AR (feet)
760
759
758
757
756
755
754
753
752
0
500
1,000
1,500
2,000
2,500
Flow at Comstock Gage (cfs)
R² = 0.938
Result
Trendline
95% Confidence Interval of Trendline

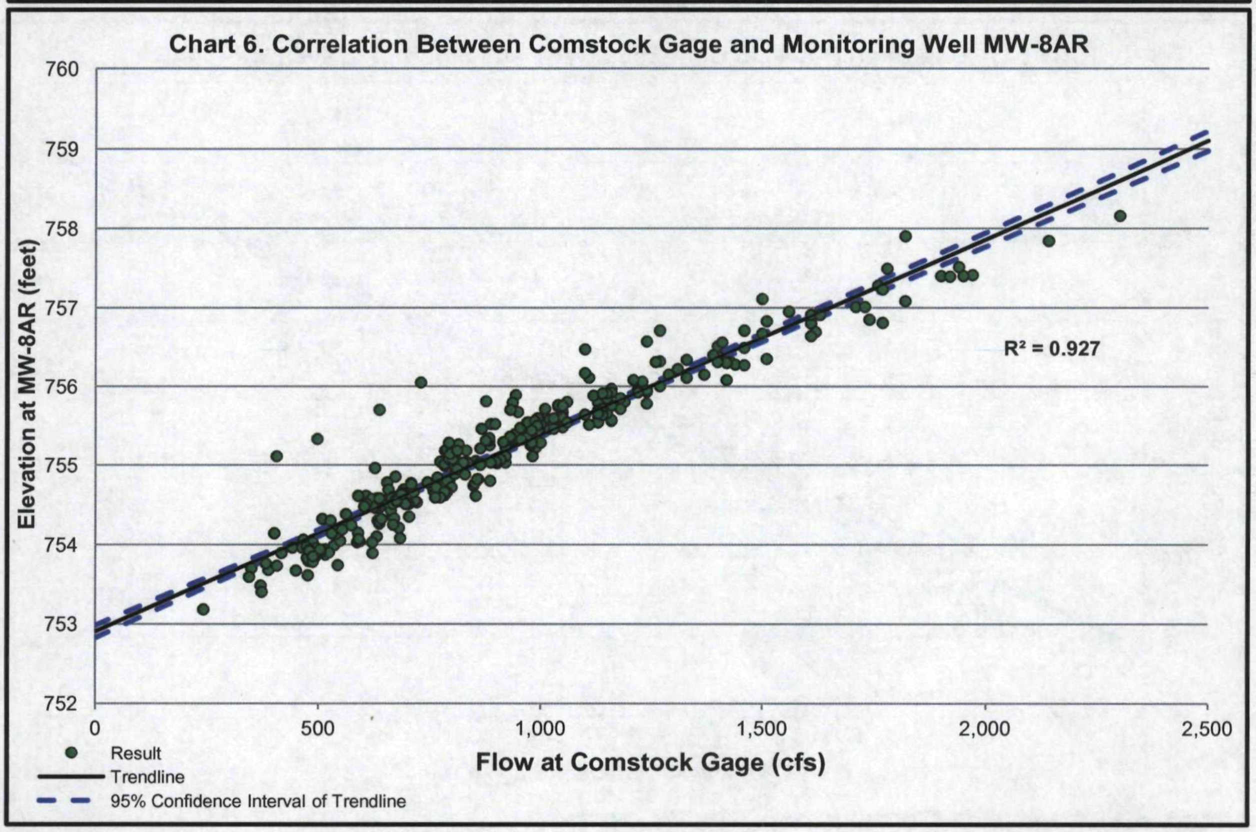


Chart 6. Correlation Between Comstock Gage and Monitoring Well MW-8AR
Elevation at MW-8AR (feet)
760
759
758
757
756
755
754
753
752
0
500
1,000
1,500
2,000
2,500
Flow at Comstock Gage (cfs)
R² = 0.927
Result
Trendline
95% Confidence Interval of Trendline

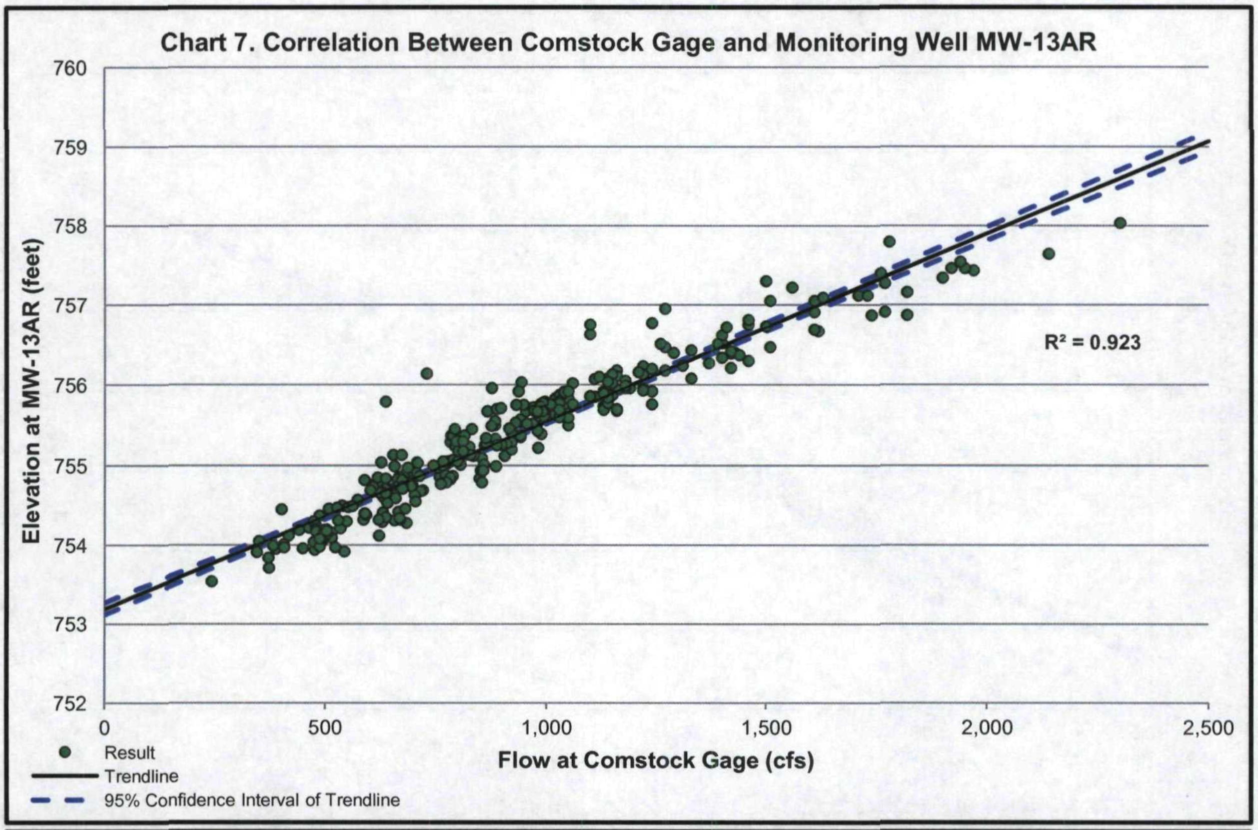


Chart 7. Correlation Between Comstock Gage and Monitoring Well MW-13AR
Elevation at MW-13AR (feet)
760
759
758
757
756
755
754
753
752
0
500
1,000
1,500
2,000
2,500
Flow at Comstock Gage (cfs)
R² = 0.923
Result
Trendline
95% Confidence Interval of Trendline

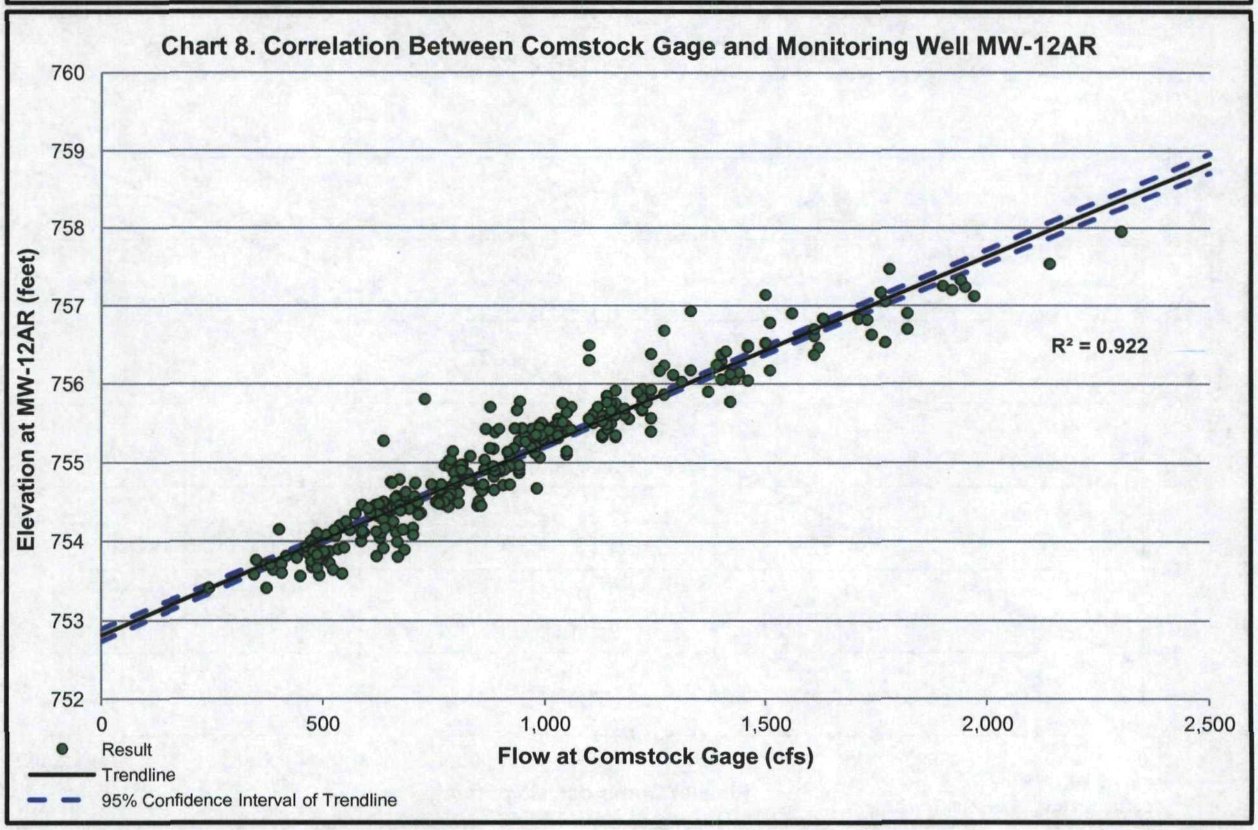


Chart 8. Correlation Between Comstock Gage and Monitoring Well MW-12AR
Elevation at MW-12AR (feet)
760
759
758
757
756
755
754
753
752
0
500
1,000
1,500
2,000
2,500
Flow at Comstock Gage (cfs)
R² = 0.922
Result
Trendline
95% Confidence Interval of Trendline

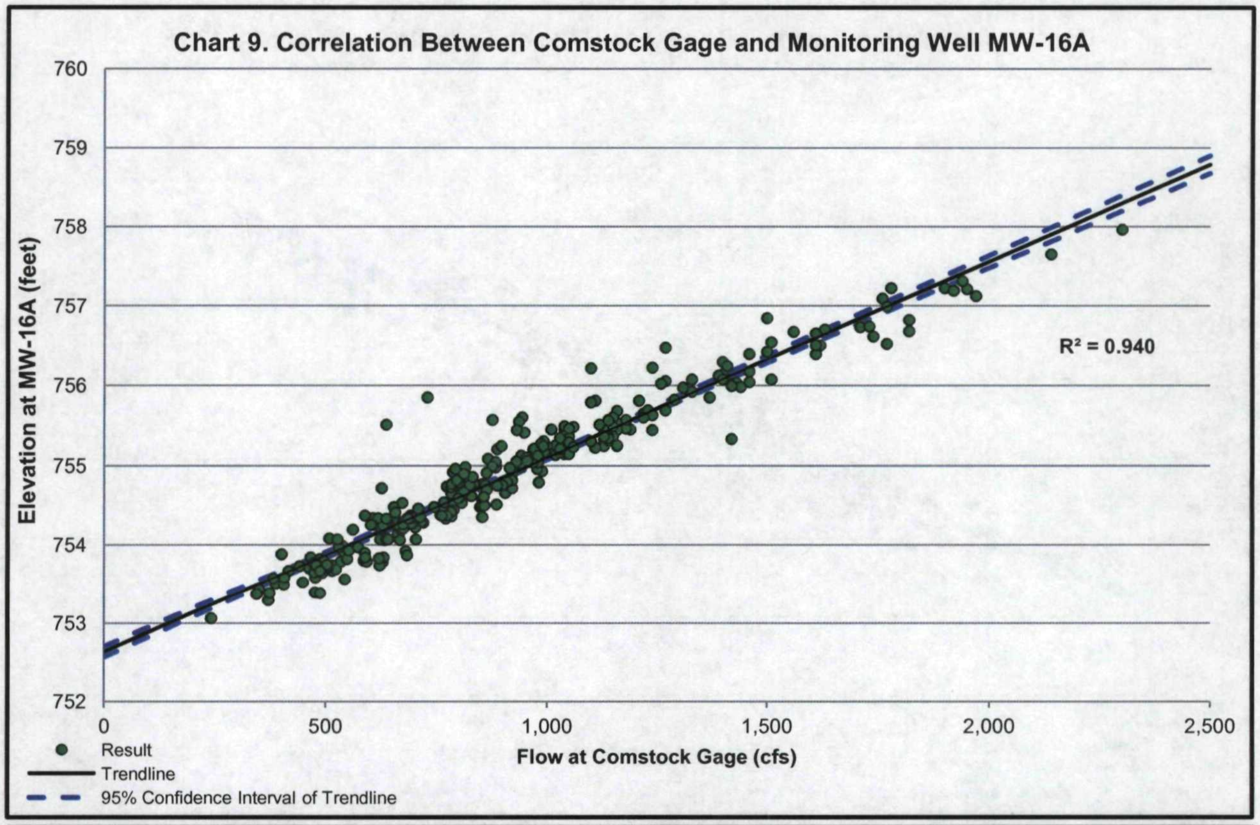


Chart 9. Correlation Between Comstock Gage and Monitoring Well MW-16A
Elevation at MW-16A (feet)
760
759
758
757
756
755
754
753
752
0
500
1,000
1,500
2,000
2,500
Flow at Comstock Gage (cfs)
$R^2 = 0.940$
Result
Trendline
95% Confidence Interval of Trendline

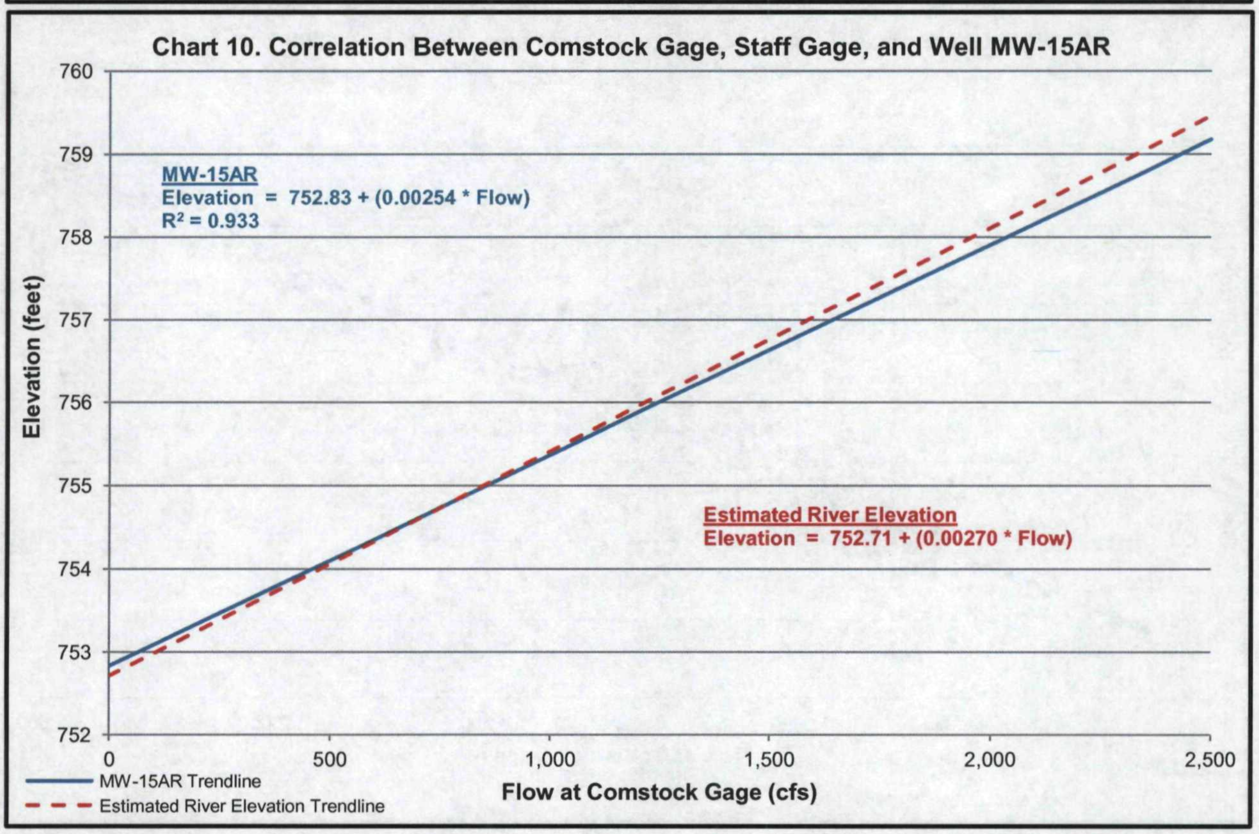


Chart 10. Correlation Between Comstock Gage, Staff Gage, and Well MW-15AR
Elevation (feet)
760
759
758
757
756
755
754
753
752
0
500
1,000
1,500
2,000
2,500
Flow at Comstock Gage (cfs)
MW-15AR
Elevation = 752.83 + (0.00254 * Flow)
$R^2 = 0.933$
Estimated River Elevation
Elevation = 752.71 + (0.00270 * Flow)
MW-15AR Trendline
Estimated River Elevation Trendline

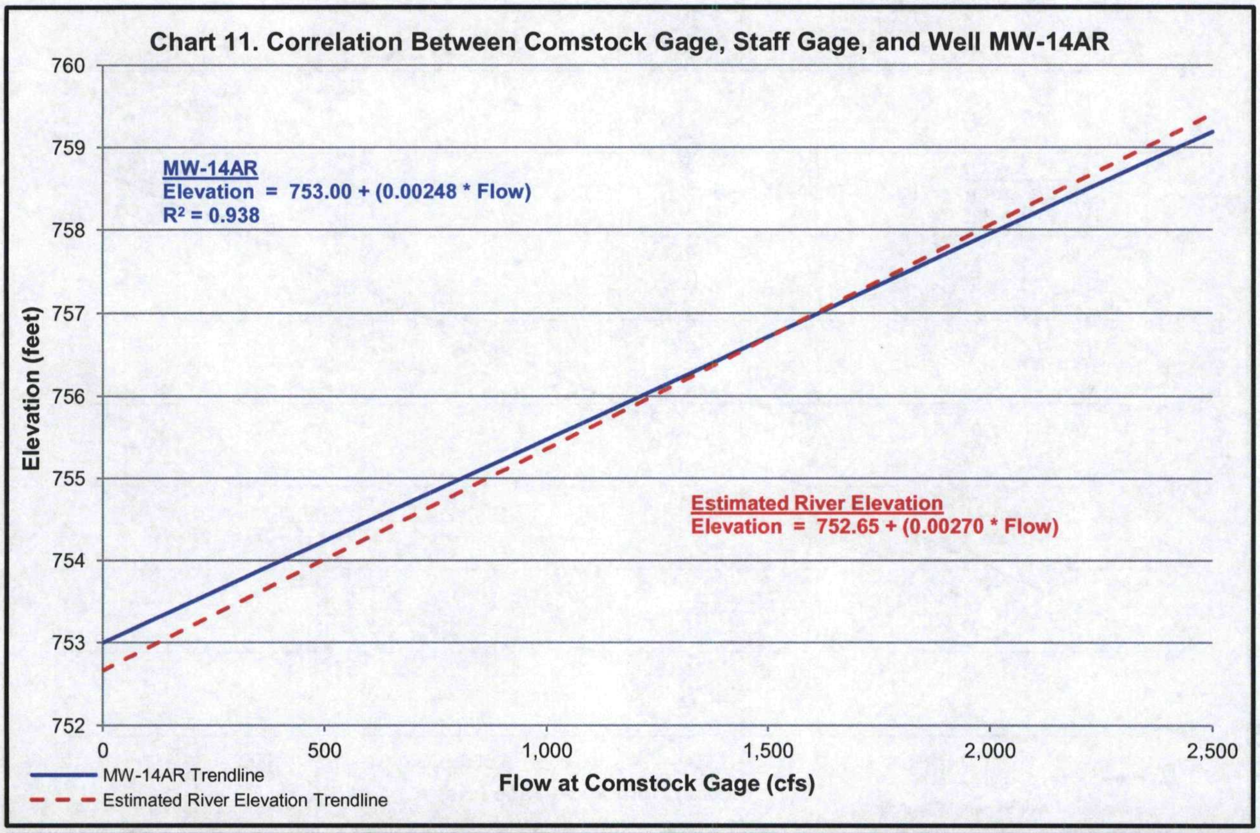


Chart 11. Correlation Between Comstock Gage, Staff Gage, and Well MW-14AR
MW-14AR
Elevation = 753.00 + (0.00248 * Flow)
R² = 0.938
Estimated River Elevation
Elevation = 752.65 + (0.00270 * Flow)
Elevation (feet)
760
759
758
757
756
755
754
753
752
0
500
1,000
1,500
2,000
2,500
Flow at Comstock Gage (cfs)
MW-14AR Trendline
Estimated River Elevation Trendline

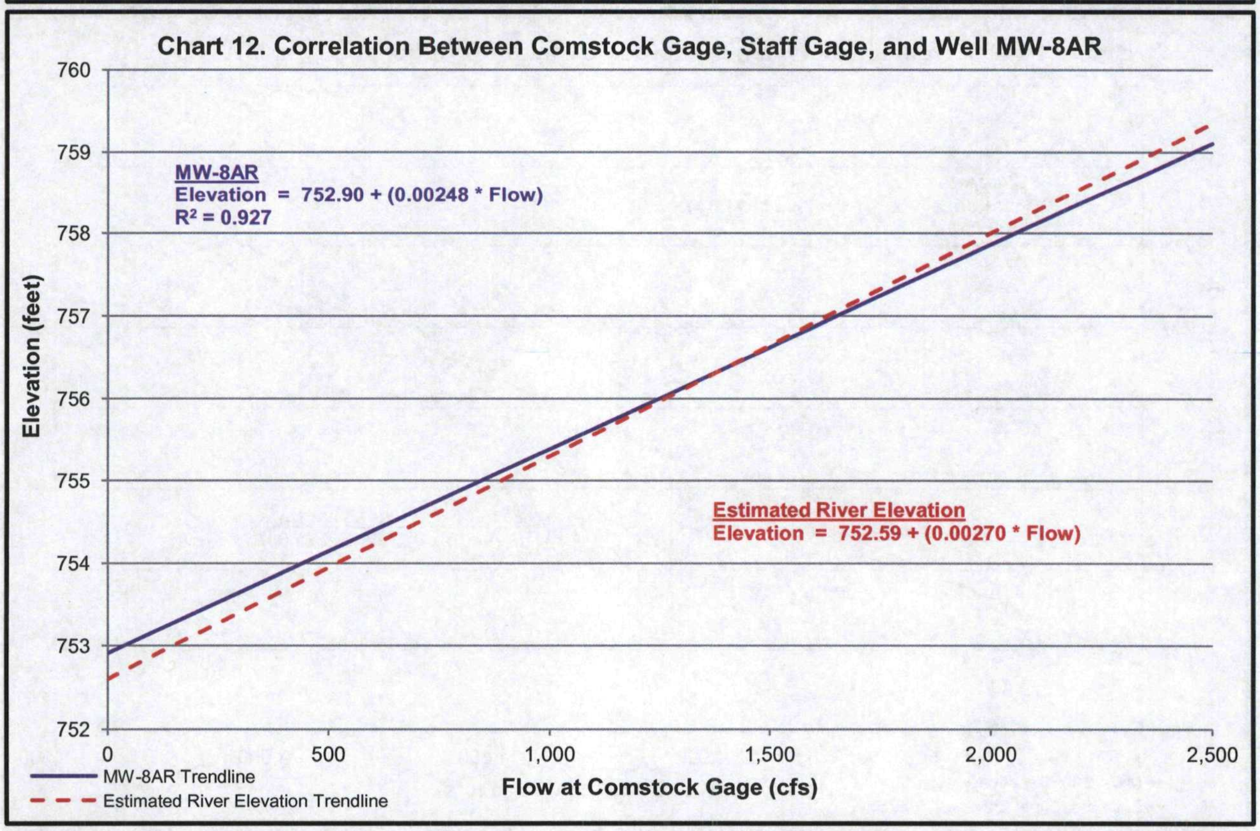


Chart 12. Correlation Between Comstock Gage, Staff Gage, and Well MW-8AR
MW-8AR
Elevation = 752.90 + (0.00248 * Flow)
R² = 0.927
Estimated River Elevation
Elevation = 752.59 + (0.00270 * Flow)
Elevation (feet)
760
759
758
757
756
755
754
753
752
0
500
1,000
1,500
2,000
2,500
Flow at Comstock Gage (cfs)
MW-8AR Trendline
Estimated River Elevation Trendline

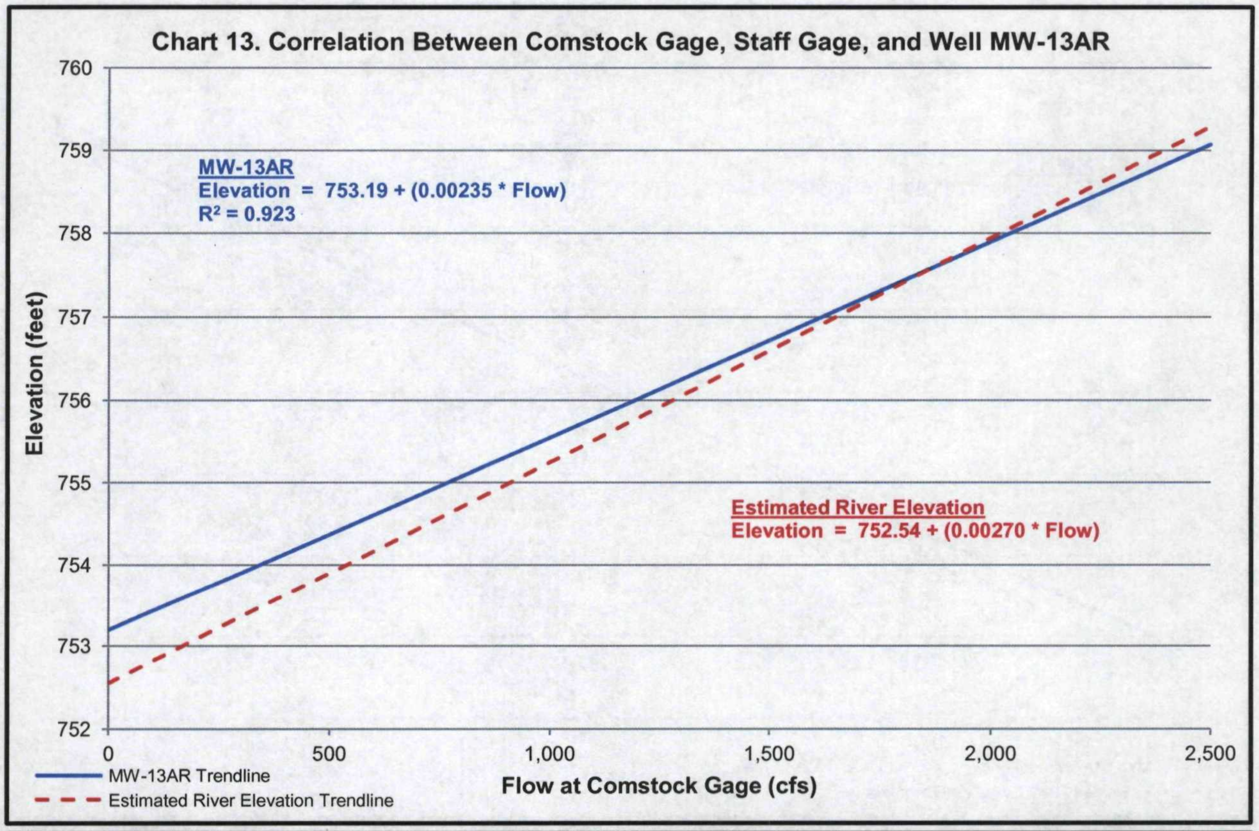


Chart 13. Correlation Between Comstock Gage, Staff Gage, and Well MW-13AR
760
759
758
757
756
755
754
753
752
Elevation (feet)
MW-13AR
Elevation = 753.19 + (0.00235 * Flow)
R² = 0.923
Estimated River Elevation
Elevation = 752.54 + (0.00270 * Flow)
0
500
1,000
1,500
2,000
2,500
Flow at Comstock Gage (cfs)
MW-13AR Trendline
Estimated River Elevation Trendline

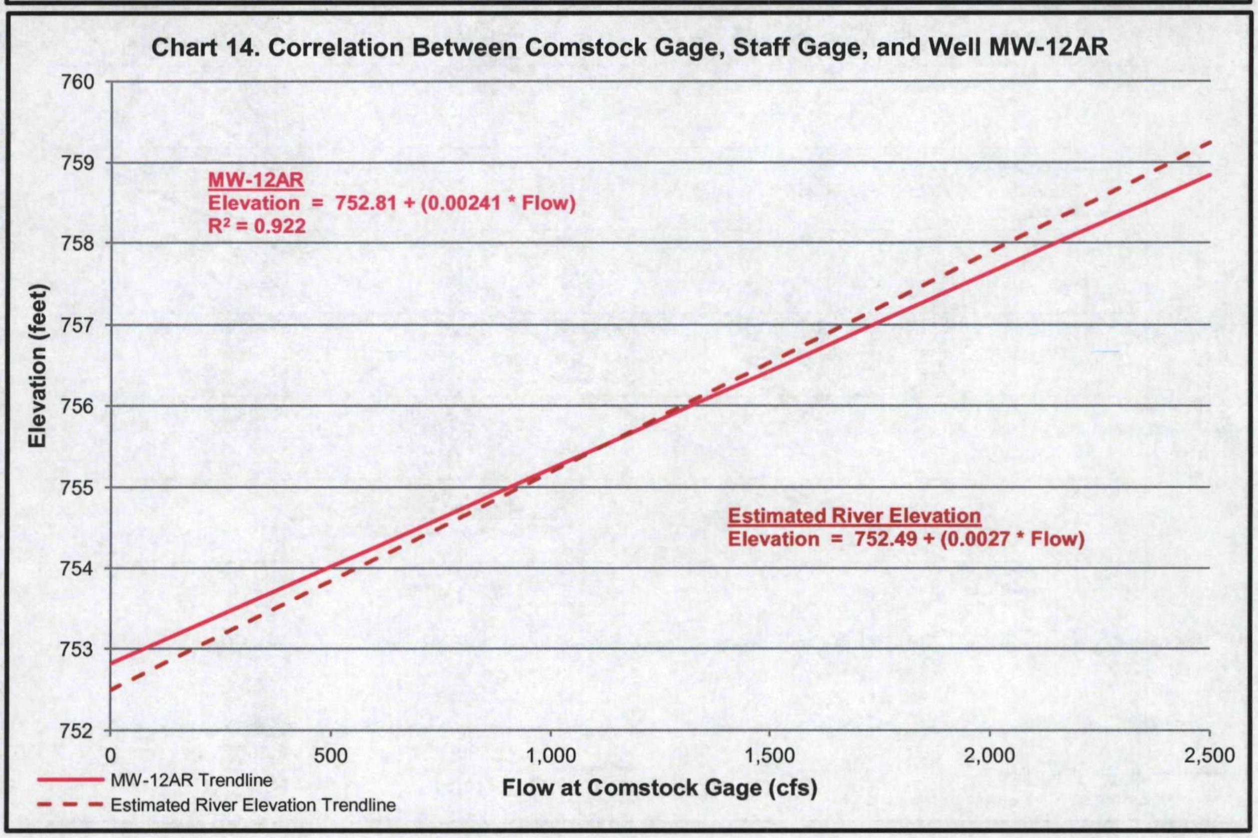


Chart 14. Correlation Between Comstock Gage, Staff Gage, and Well MW-12AR
760
759
758
757
756
755
754
753
752
Elevation (feet)
MW-12AR
Elevation = 752.81 + (0.00241 * Flow)
R² = 0.922
Estimated River Elevation
Elevation = 752.49 + (0.0027 * Flow)
0
500
1,000
1,500
2,000
2,500
Flow at Comstock Gage (cfs)
MW-12AR Trendline
Estimated River Elevation Trendline

Chart 15. Correlation Between Comstock Gage, Staff Gage, and Well MW-16A